# Precision measurement of the Z boson to electron neutrino coupling at the future circular colliders*

« …making the neutrino flavor visible in Z decays »

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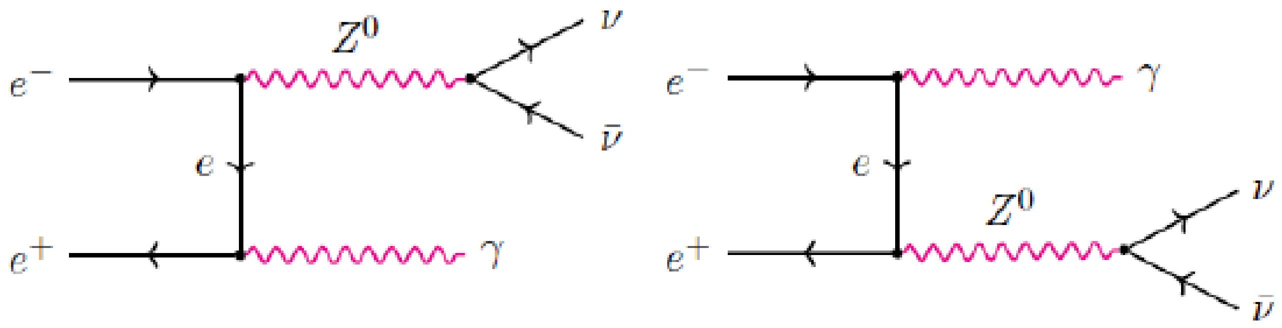
https://arxiv.org/abs/1908.06338




Neutrino counting measured at LEP with/without radiative γ : $N_\nu = 2.984 \pm 0.008$

$\sigma(e^+e^- \to Z \to \text{invisible}) =$
$(g_Z^{\nu_e}\mathcal{A}_Z^{\nu_e})^2 + (g_Z^{\nu_\mu}\mathcal{A}_Z^{\nu_\mu})^2 + (g_Z^{\nu_\tau}\mathcal{A}_Z^{\nu_\tau})^2 + (g_Z^{X}\mathcal{A}_Z^{X})^2$

**No distinction between neutrino flavor**

# Motivation : Complementing tests of lepton universality

$$\Delta_W^{\tau/\ell} = BR(W \to \tau\nu) - BR(W \to \ell\nu) = 0.00711 \pm 0.00237 \qquad (PDG: \approx 3\sigma) \qquad (\ell = e, \mu)$$

$$R_{D*}^{\tau/\ell} = \frac{BR(B\to D^*\tau\nu)_{exp}/BR(B\to D^*\tau\nu)_{SM}}{BR(B\to D^*\ell\nu)_{exp}/BR(B\to D^*\ell\nu)_{SM}} = 1.28 \pm 0.08 \qquad (3.8\ \sigma)$$

$$R_{D}^{\tau/\ell} = \frac{BR(B\to D\tau\nu)_{exp}/BR(B\to D\tau\nu)_{SM}}{BR(B\to D\ell\nu)_{exp}/BR(B\to D\ell\nu)_{SM}} = 1.37 \pm 0.18 \qquad (2.0\ \sigma)$$

$$R_{K}^{\mu/e} = \frac{BR(B\to K\mu^+\mu^-)_{exp}}{BR(B\to Ke^+e^-)_{exp}} = 0.745 \pm 0.080 \pm 0.036 \qquad (2.6\ \sigma)$$

$$= 0.846\ ^{+0.060}_{-0.054}\ ^{+0.016}_{-0.014}(syst) \qquad (2.5\sigma)$$

$g_Z^{\nu_e}$ poorly measured

PDG $\left\{ \begin{array}{l} g_Z^{\nu_e} = 1.06 \pm 0.18 \\ g_Z^{\nu_\mu} = 1.004 \pm 0.034 \end{array} \right.$

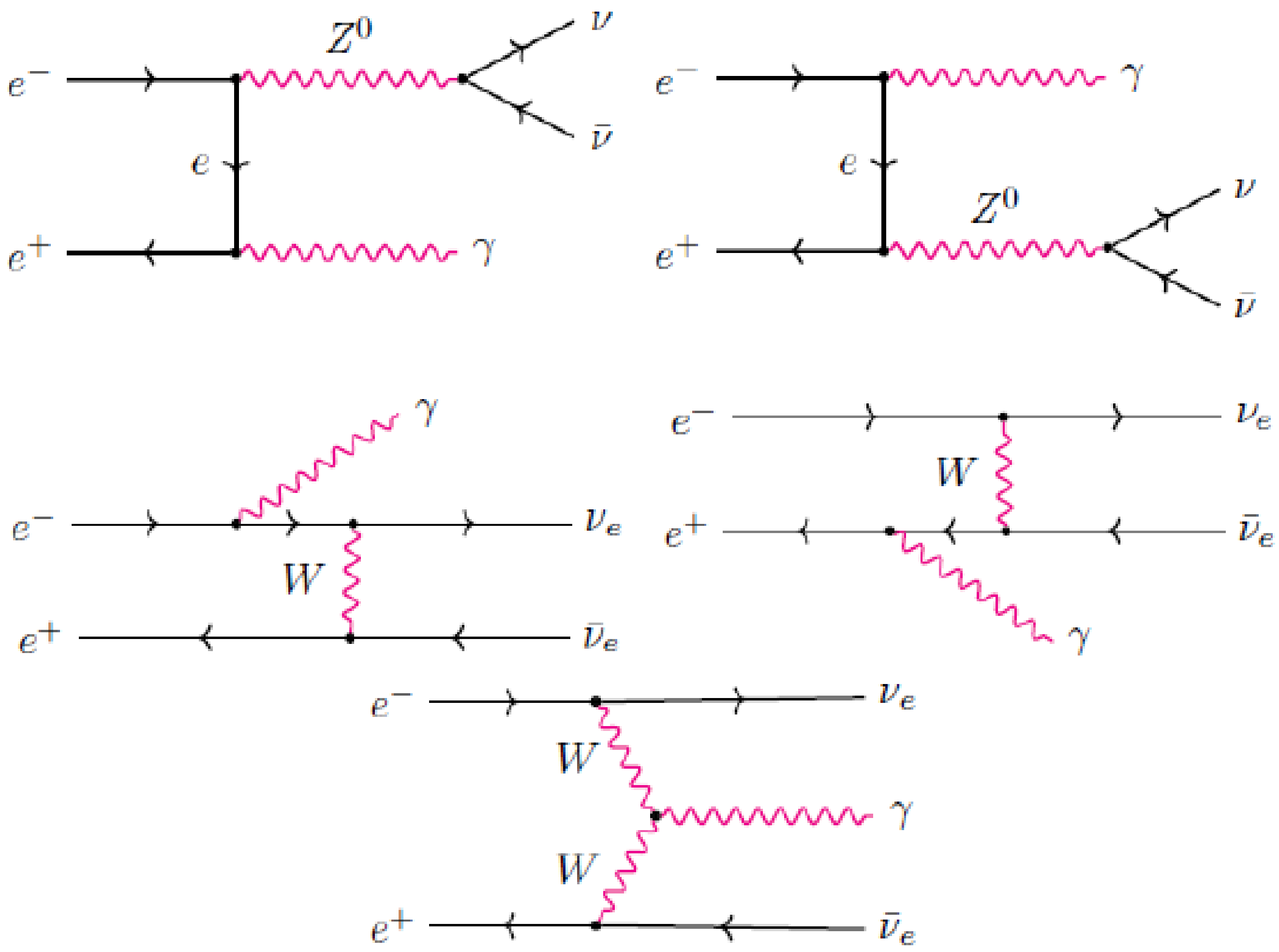
From $\nu_\mu$ e and $\nu_e$ e scattering

$g_Z^{\nu_\tau}$ = ?

How to do better at FCC-ee?

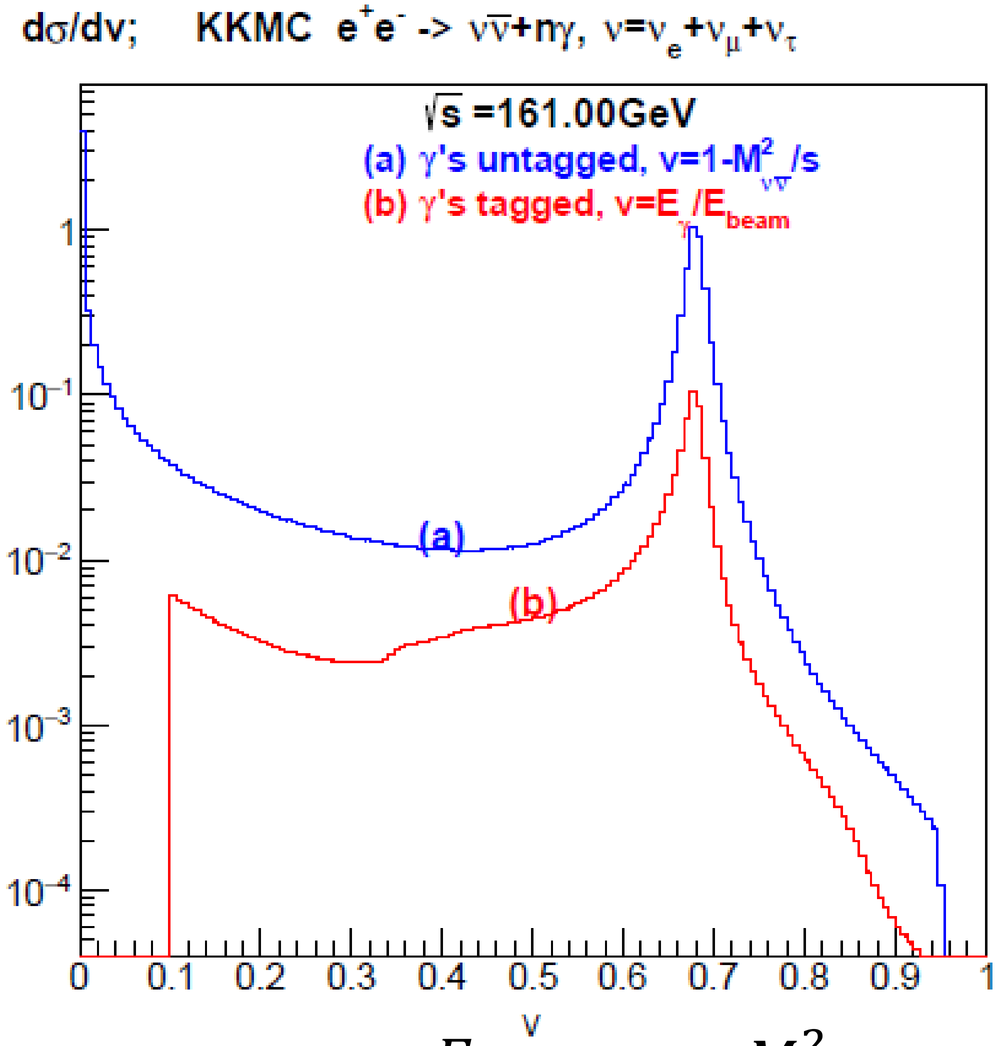
In the following we assume $N_{inv} \equiv 3\ \nu$ since will be measured at FCC with negligible error

# Search for interference with diagrams with well known couplings




Only $\nu_e$ interfere ⇨ interference effect measures $g_Z^{\nu_e}$

We concentrate on $\sqrt{S} = 161\ GeV$ with L=10ab$^{-1}$ (i.e. with 2 detectors)
MC used KKMC (see Staszek Jadach et al.)

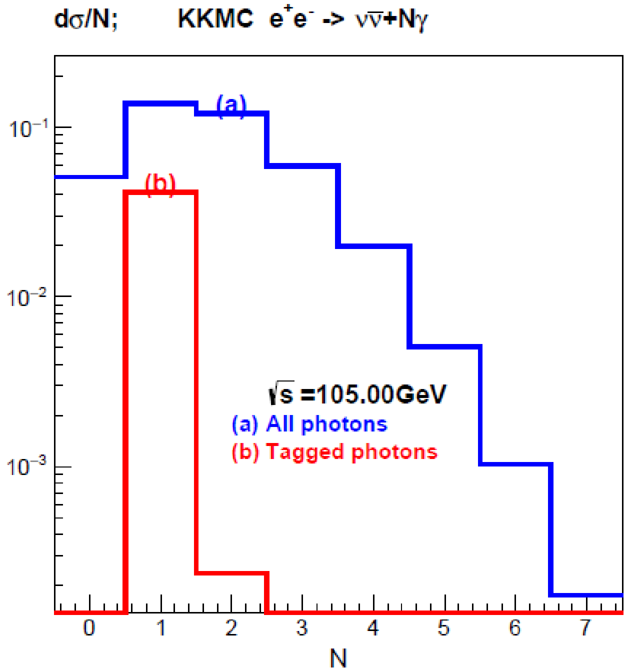



$$\mathcal{V} = \frac{E_\gamma}{E_{beam}} \approx 1 - \frac{M_{\nu\bar{\nu}}^2}{s}$$

Cuts for **(b)** curve

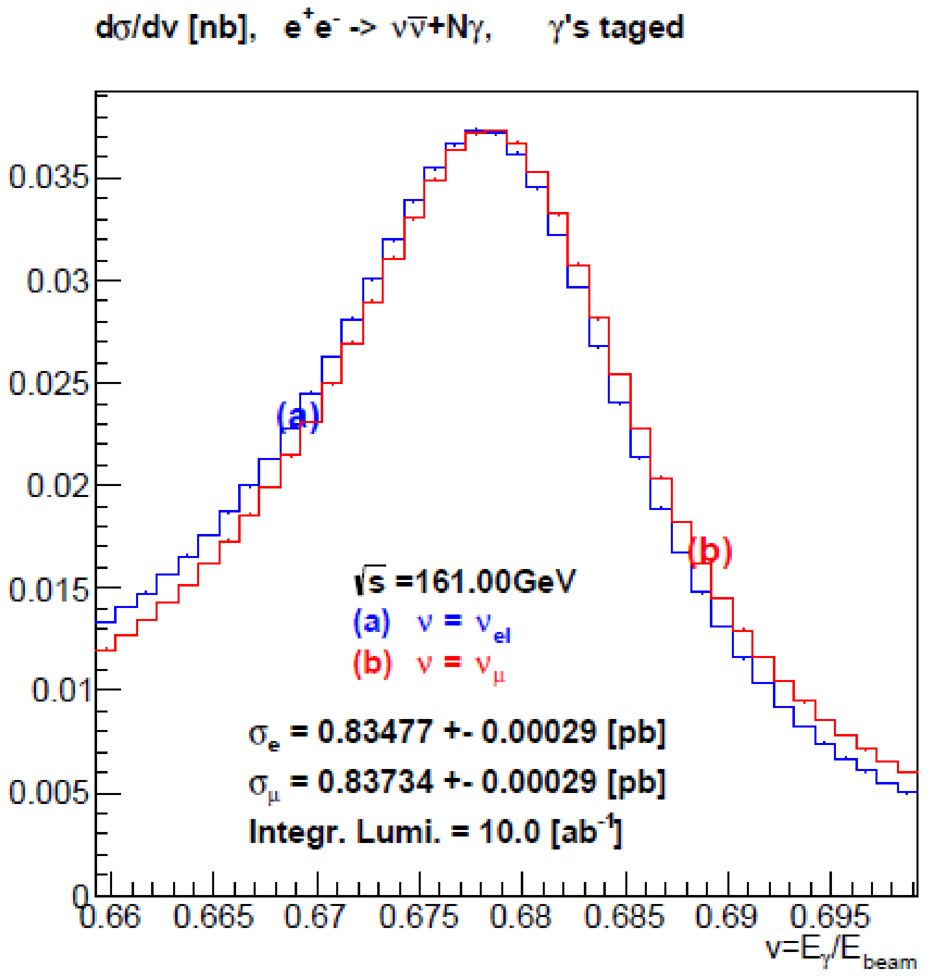
$$\sum E_\gamma > 0.1 E_{beam}$$
$$\theta_\gamma > 15°$$
$$E_{T\gamma} > 0.02\ E_{beam}$$

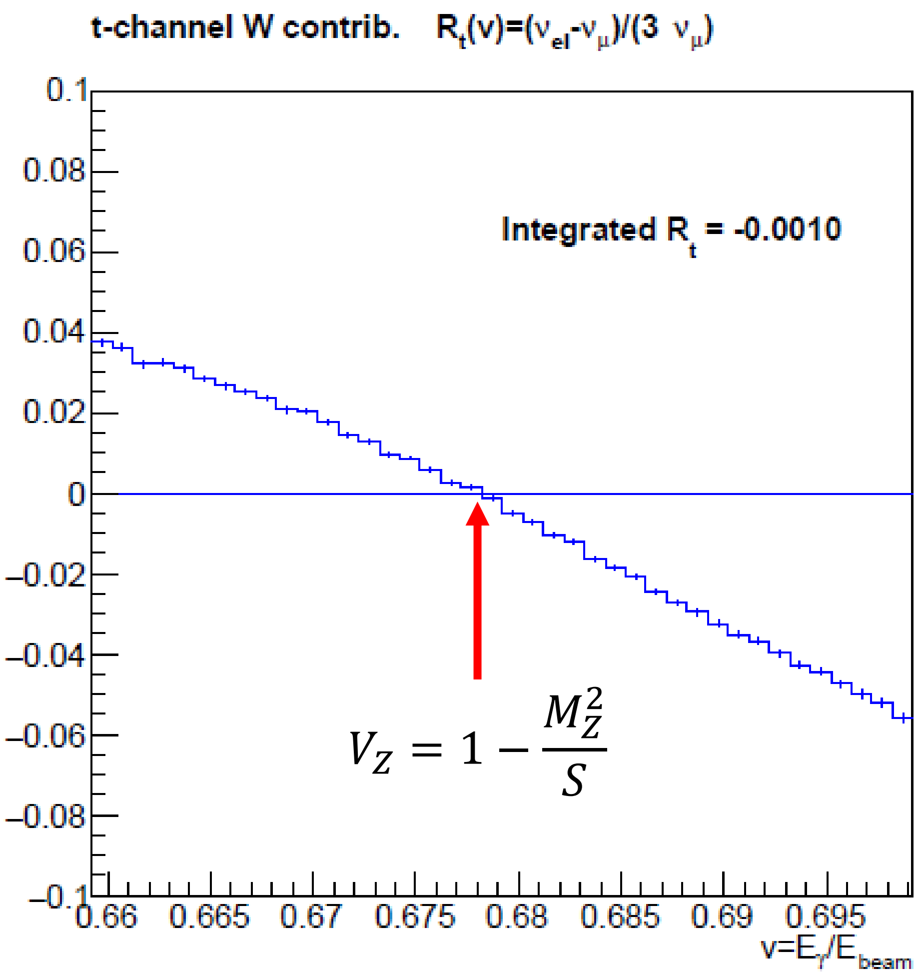
Essentially 1 γ after cuts



# Zoom on Z Radiative Return (ZRR)

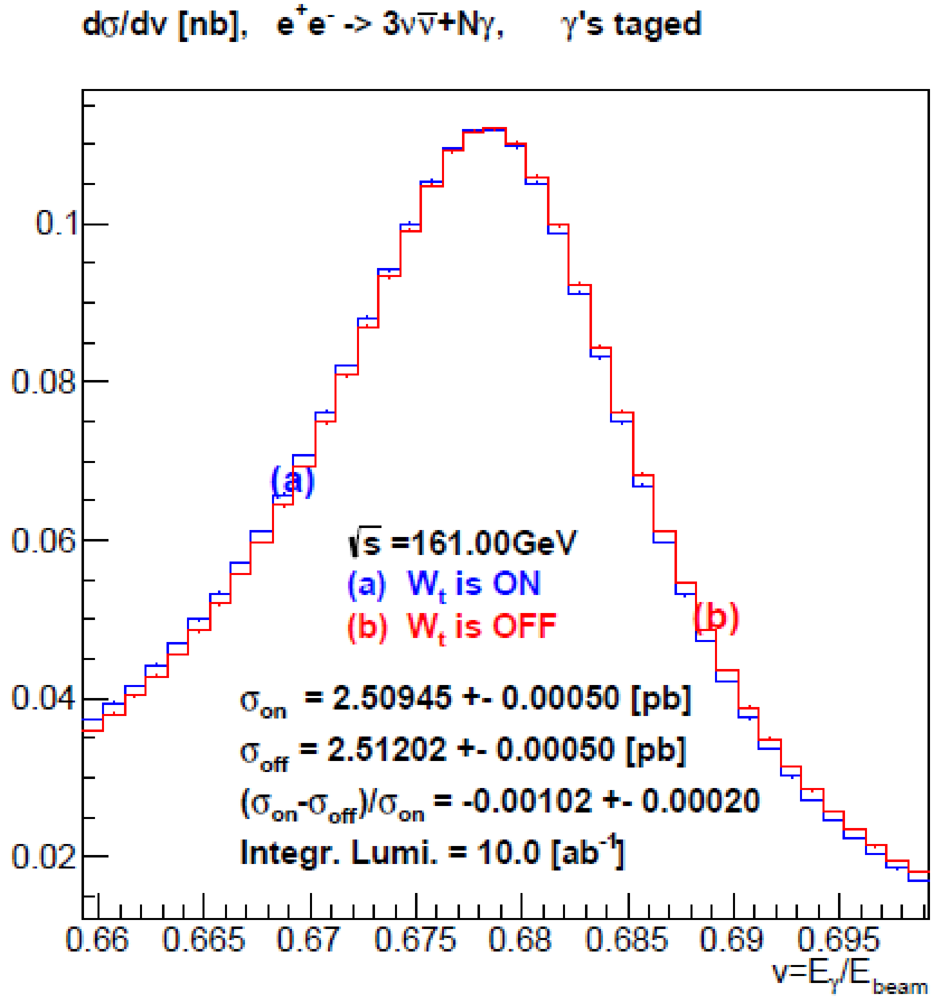
Difference between $\nu_{\mu(\tau)}$ and $\nu_e$

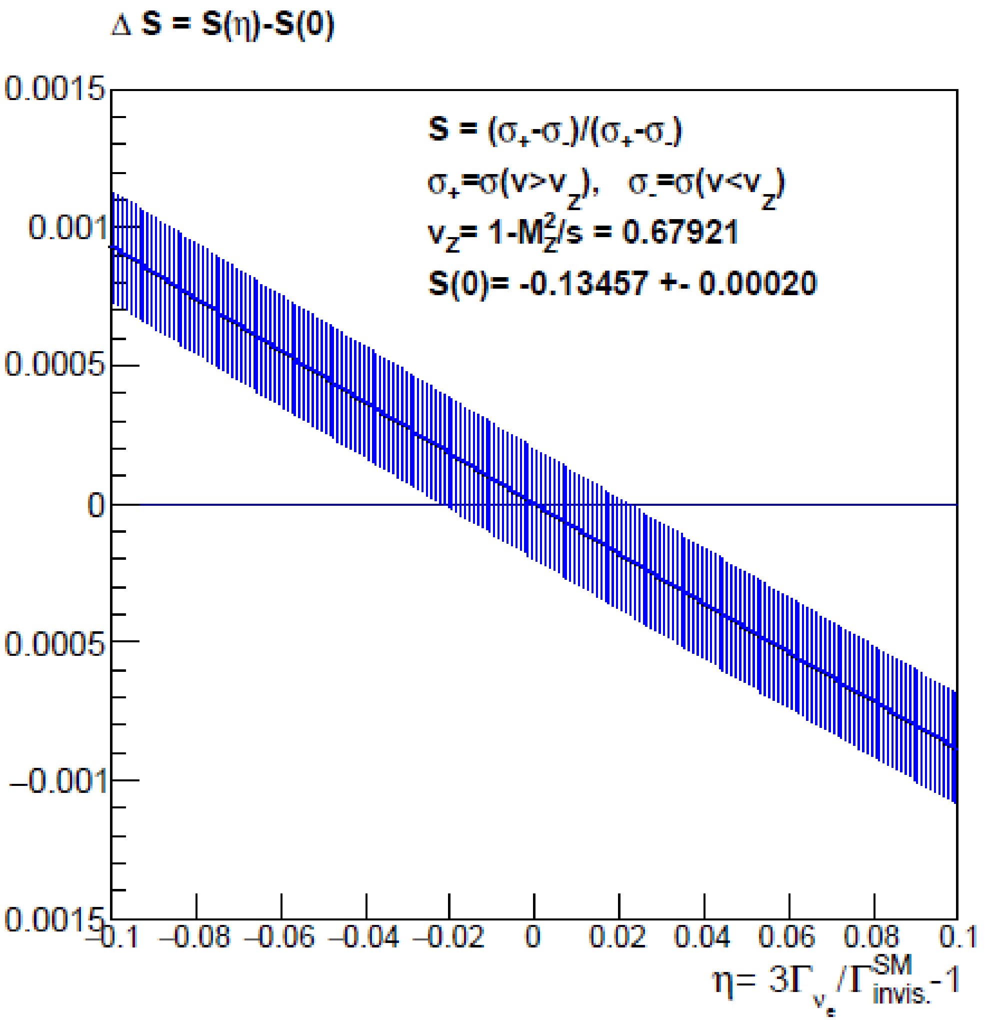



$$V_Z = 1 - \frac{M_Z^2}{S}$$

Interference effects may look small but
Huge statistics is available ~25 x $10^6$ events

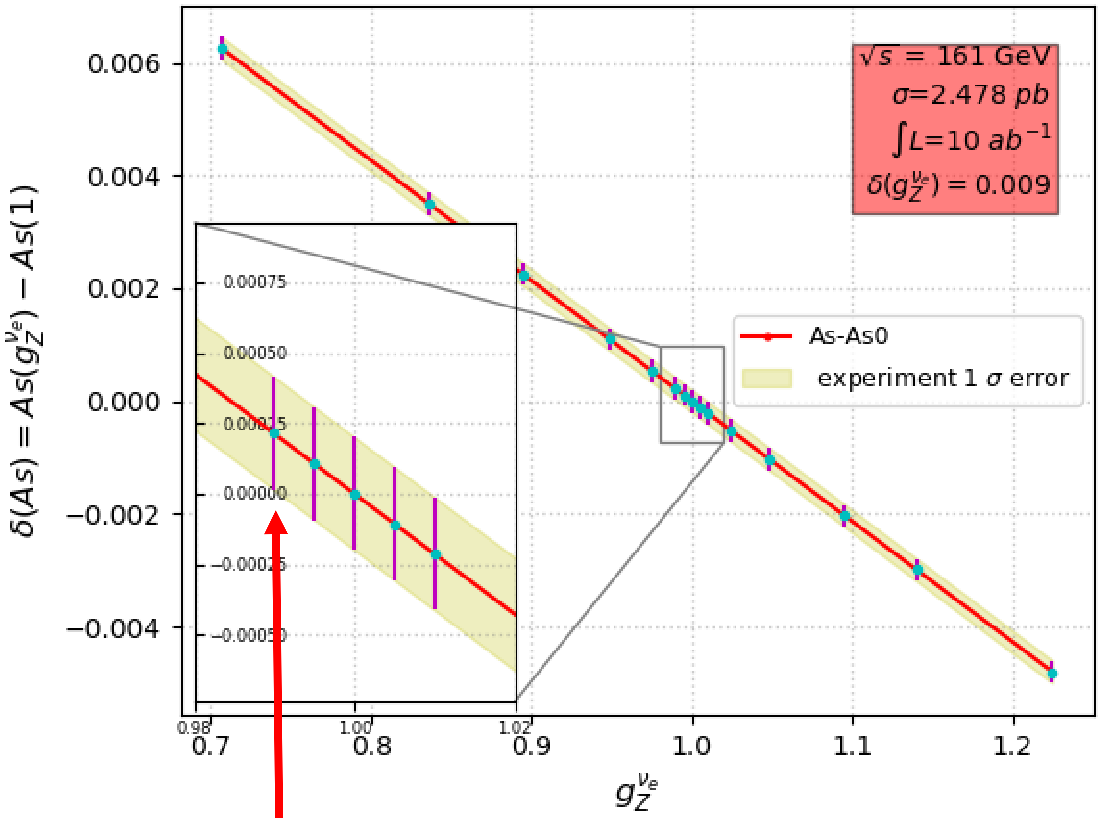



Parametrization assuming $N_{inv} \equiv 3\,\nu$ ⇨ $g_Z^{\nu_e} = \sqrt{1+\eta}\,,\, g_Z^{\nu_\mu} = 1\,,\, g_Z^{\nu_\tau} = \sqrt{1-\eta}$

## Error on $g_Z^{\nu_e}$

Without detector resolution dilution effects

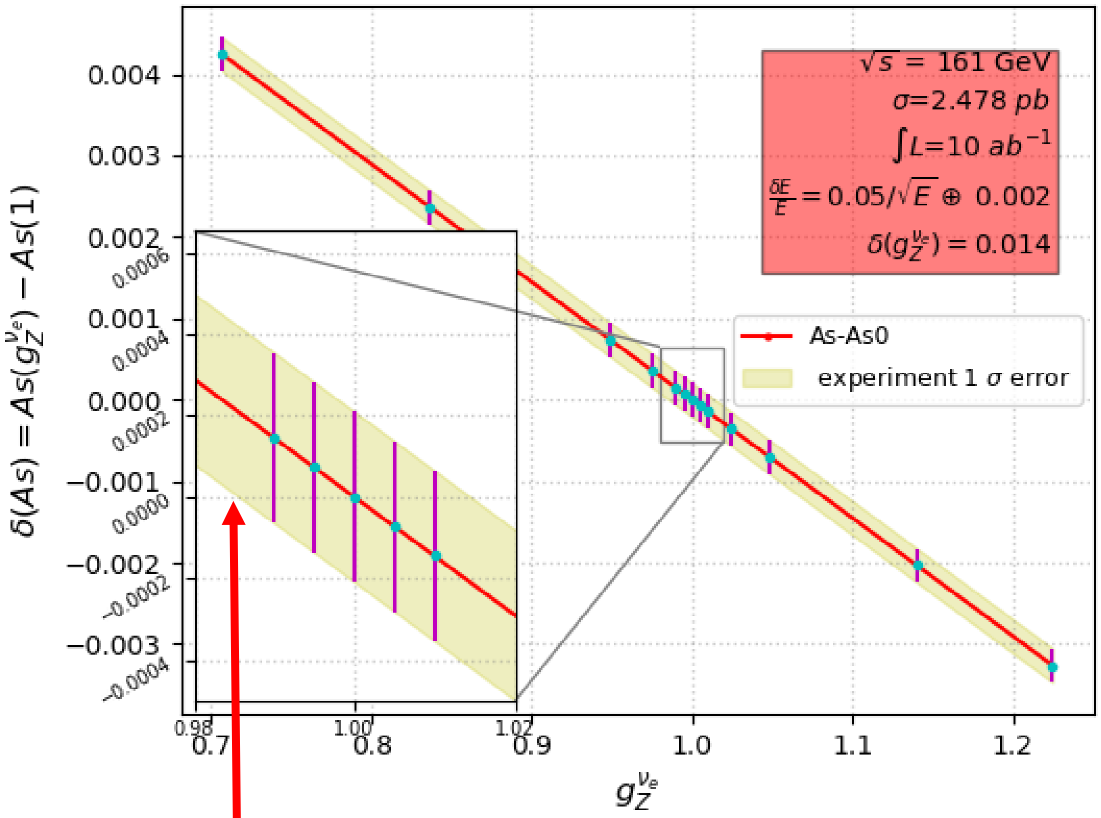



$\delta(g_Z^{\nu_e}) = \pm 1.0\%$

With detector resolution dilution effects

$$\frac{\delta E_\gamma}{E_\gamma} = \frac{0.05}{\sqrt{E_\gamma}} \oplus 0.002$$

Can be calibrated with μμγ events




$\delta(g_Z^{\nu_e}) = \pm 1.4\%$

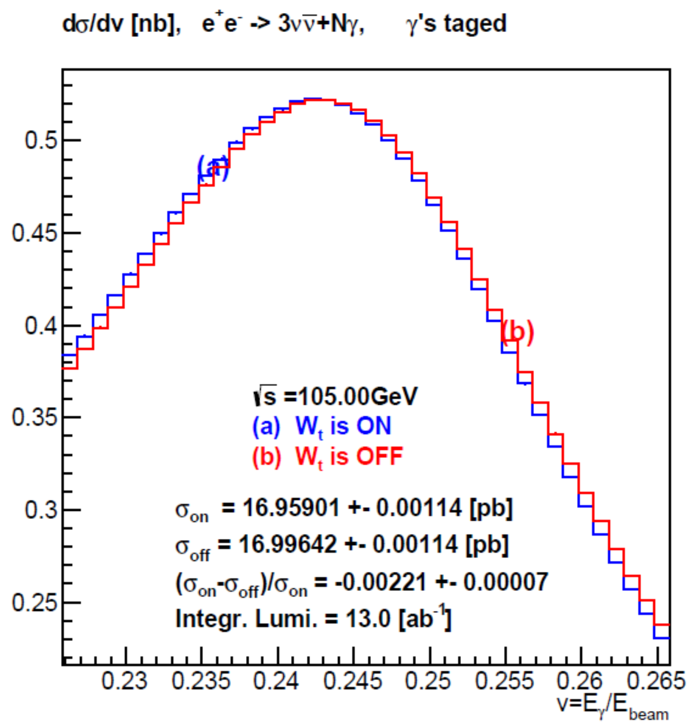
If stochastic term x2 ⇨ $\delta(g_Z^{\nu_e}) = \pm 2.4\%$

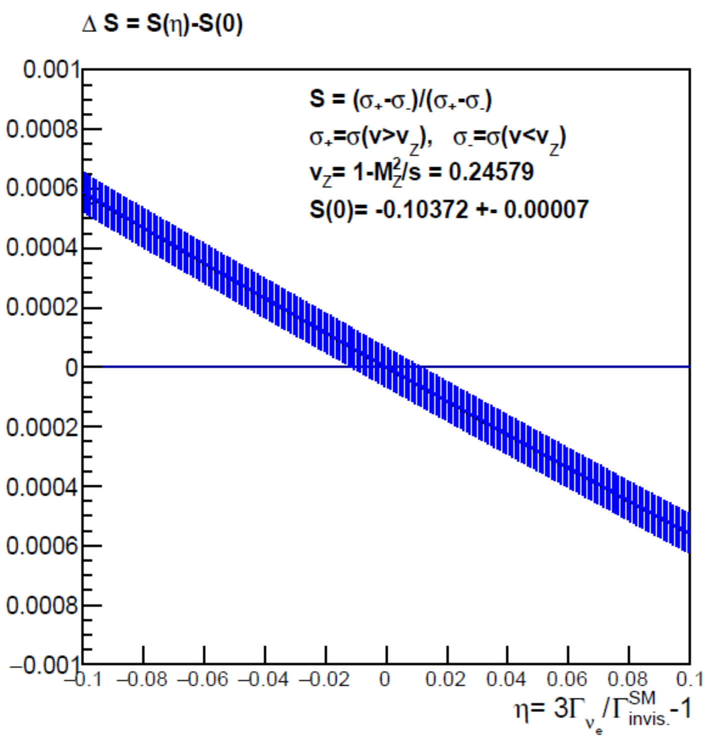
# Summary

- The method proposed would lead to a considerable improvement on the presicion on $g_Z^{\nu_e}$

  ⇨ $\delta(g_Z^{\nu_e}) = \pm 1.4\%$
- Assuming 3 ν and no new physics coupled to Z, one would derive

  ⇨ $\delta(g_Z^{\nu_\tau}) = \pm 4.8\%$
- $\sqrt{S} = 161\ GeV$ not optimal (but we will run there anyway), e.g. 6 months at $\sqrt{S} = 105\ GeV$ would allow for twice smaller errors



## Final remarks :
## This is a preliminary study and several complementary studies needed

- virtual corrections for W contribution in KKMC matrix element has to be checked
- the size and shape of the QED deformation of the Z peak in ZRR obtained from KKMC should be cross-checked using independent calculation
- EW corrections were included in the presented KKMC calculation - their size and role should be examined quantitatively
- dominant $O(\alpha^3)$ QED non-soft corrections (in our convention) should be estimated/calculated.

There are also several other improvements in the analysis front, which needs to be studied:

- carrying a full fit of the v spectrum instead of measuring its asymmetry
- optimizing the v range.
- study of the interference effect at low and high v range might be useful to improve the sensitivity on $g_Z^{\nu_e}$
- Carrying an analysis with full detector simulation will be ultimately needed